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ECE3161 Report

Ultrasonic Reverse Sensor with Audible and Visual Distance Detector

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1 Inspiration:

Reversing is a critical manoeuvre during vehicle operation. Monash University Accident Research Centre (MUARC) conducted a study in 2014 on "Camera Effectiveness and Back over Collisions with Pedestrians: A Feasibility Study" [1]. The study revealed that vehicles equipped with advanced reverse sensing technology are less likely to be involved in back-over collisions with pedestrians and cyclists.

The problem that inspired us for this project is that we recognized the limitations of solely relying on rear-view mirrors when reversing in a vehicle as well as the hazards of blind spots while reversing.

Hence, our objective is to enhance driver situational awareness and reduce the likelihood of collisions by designing an Audible and Visual Distance Detection System.

2 Abstract:

This project report presents the design and implementation details of an Audible and Visual Distance Detector.

The objective of the project is to detect the presence of objects when reversing a vehicle. Then if the object detected is within a tuneable range, the system will produce a pulsing beep with a frequency that increases as the distance to the object decreases.

The report includes a thorough explanation of each circuit block, design considerations, component values, simulation results, measurement results, a comparison between the two and a cost analysis.

3 Input Signal

The input signal is obtained by utilizing an ultrasonic sensor to provide a voltage signal corresponding to the measured distance. The input signal ranges from 0 to 4 volts, corresponding to 0 to 0.5 meters. The voltage-to-distance mapping is based on sensor characteristics [2] and desired range for demo purposes.

4 Circuit Design and Implementation:

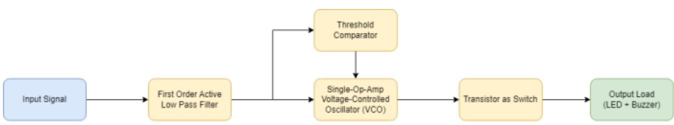

Figure 1: Complete Block Diagram of System

The design approach involves using an active low-pass filter to remove high-frequency noise, a comparator to determine if the object is within the range, and a voltage-controlled oscillator to generate an oscillating wave dependent on the distance of detection. The oscillating wave is then connected to a transistor as a switch to control the load (LED and Buzzer).

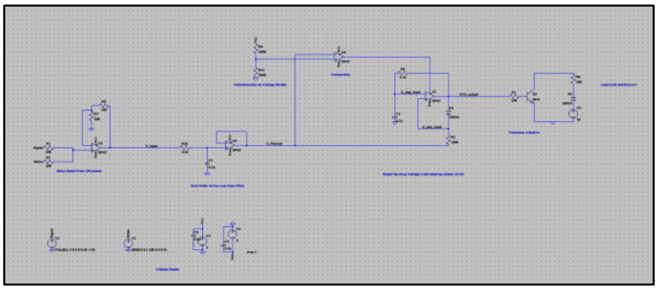

Figure 2: Complete Circuit Diagram in LTSpice

4.1 1st Order Active Low-Pass Filter:

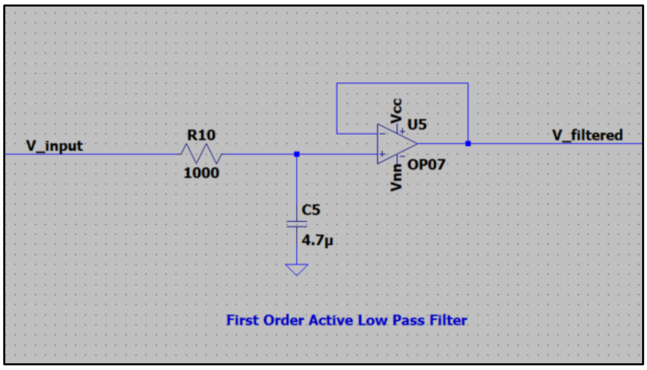

Figure 3: First Order Active Low-Pass Filter (LTSpice)

4.1.1 Function of Low-Pass Filter

The decision to utilize a First Order Active Low-Pass filter was motivated by its simplicity and cost-effectiveness. This filter type offers an uncomplicated design that consists of a single reactive component, a 4.7µF capacitor, and one resistive element, a 2200 Ω resistor.

Given that the input signal is in range of 0 to 4 volts. There is no need for signal amplification as the clipping voltage of the operational amplifier is already at 5 volts. However, an active low-pass filter that consists of an operational amplifier was chosen rather than a passive one was due to its several advantages in terms of signal conditioning and noise reduction.

An active low-pass filter has a higher input impedance than a passive filter. The input impedance of an active low-pass filter is determined by the operational amplifier, which is much higher than that of a passive low-pass filter, where its input impedance is only determined by the values of the resistor and capacitor used. Lower input impedance can cause loading effects on the input signal, which can distort the signal and affect the quality of the signal coming to next components.

The higher input impedance of an active low-pass filter means that it will not load the input signal and will therefore provide a more accurate representation of the original signal. This is important in the reverse car sensor system, as the input signal is used to control the braking and reversing of the car. A distorted signal could lead to inaccurate braking or reversing, which could potentially cause an accident.

4.1.2 Circuit Analysis

The low cut off frequency can be determined by the formula, $f = \frac{1}{2\pi RC}$. Considering the presence of potential ambient outside noises, such as whistling or car pneumatic brake system, it is essential to select appropriate components that can mitigate their impact on the input signal [7]. with the given components. After evaluating various options and testing multiple times, we determined that utilizing a resistor with a value of 270 Ω and a capacitor with a value of 4.7µF would yield a cut-off frequency of 125Hz, as determined by the formula. This combination was deemed the most suitable for our specific case.

$$f = \frac{1}{2\pi RC}$$

$$= \frac{1}{2 * \pi * 270\Omega * 4.7\mu\mathrm{F}}$$

$$= 125.4176 \approx 125\ Hz$$

4.1.3 Results and Simulations

The figures below show the comparator output against a simple noisy signal.

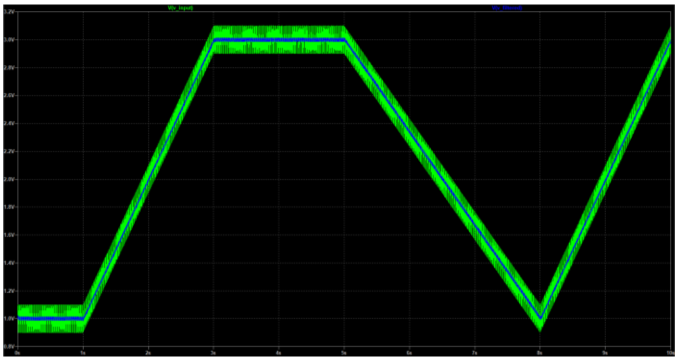

Figure 4: Comparator Output vs Noisy Input Signal Graph (LTSPICE)

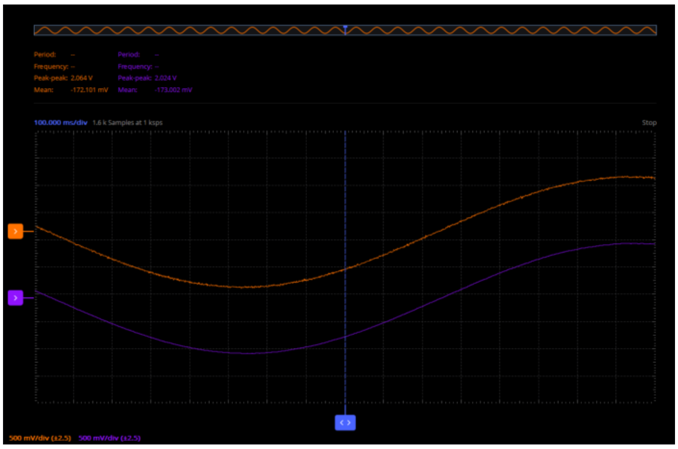

Figure 5: Comparator Output vs Noisy Input Signal Graph (Scopy)

As explained during the circuit analysis, the Active low pass filters are used to remove high frequency noise from the noisy signal. Hence it can be seen that the amplitude of the noise is greatly reduced, and the signals appear to be smoother. This is exceptionally prominent in the Scopy signal. The orange signal has noise which can be smoothen by the low pass filter resulting in the blue signal. The Bode plot below highlights that the gain for high frequencies in the signal is very low which cause the high frequency responses to be removed resulting in a smooth signal.

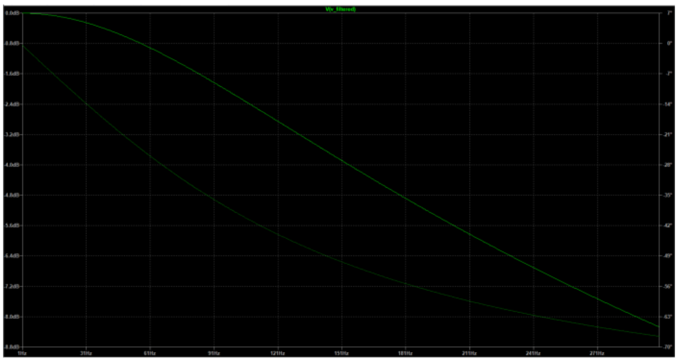

Figure 5: Bode Plot of the Filter

As shown above, the signals with high frequency are filtered out and only the signals with low frequency are passed through.

The figure Below shows the transfer function of the filtered signal against the unfiltered signal.

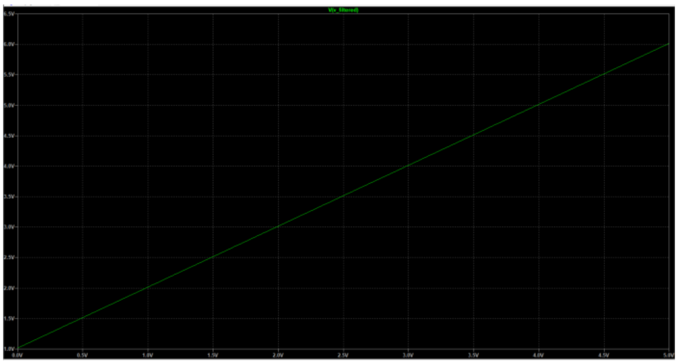

Figure 6: Transfer Function of Filter vs Unfiltered Signal (LTSpice)

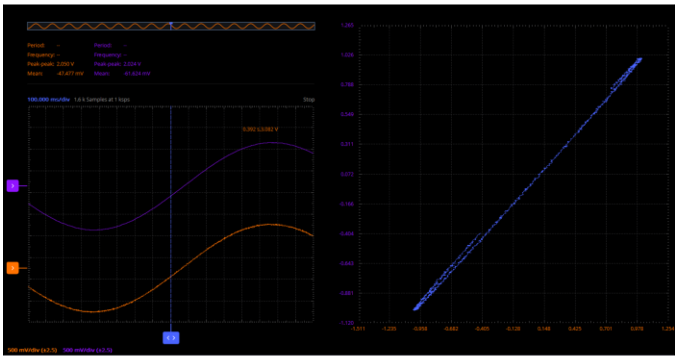

Figure 8: Transfer Function of Filter vs Unfiltered Signal (Scopy)

The transfer function above clearly shows a linear relationship between the unfiltered signal and the filtered signal. The gradient is close to 1 which is as expected since there is no amplification applied to the signal.

4.2 Comparator:

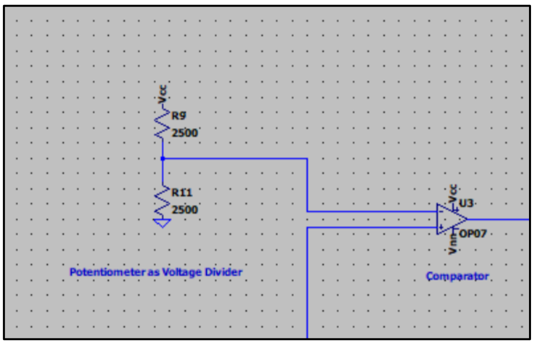

Figure 8: Comparator (LTSpice)

4.2.1 Function of Comparator

The comparator above takes two signals as inputs, the non-inverting input and the inverting input. The threshold signal is applied to the non-inverting input and the filtered ultrasonic signal is applied to the inverting input. The output of the comparator is a high signal if the filtered ultrasonic signal is greater than the threshold signal and a low signal if the filtered ultrasonic signal is less than the threshold signal.

4.2.2 Circuit Analysis

The threshold signal is controlled by a 5kΩ potentiometer. The potentiometer is a variable resistor that can be used to adjust the value of the threshold signal. The threshold signal can be adjusted to set the range of the ultrasonic sensor.

The comparator compares the filtered ultrasonic signal with the threshold value. If the signal is below the threshold, it indicates that the wall is within the detection range and thus output a high to the VCO power supply input hence turning the VCO on. Vice versa, if the signal from the sensor is higher than the threshold it shows that the wall is not with detection range rendering the VCO component to be off.

The detection range distance can be manipulated by using the following formula, $distance = \frac{V}{4} * 0.5$, giving maximum detection range to be 0.5 meters when the threshold is set at 4V. The range can be manipulated to be less by tuning the potentiometer thus reducing the range for sensor to start beeping.

4.2.3 Results and Simulations

The figures below show the comparator output against a simple sine signal.

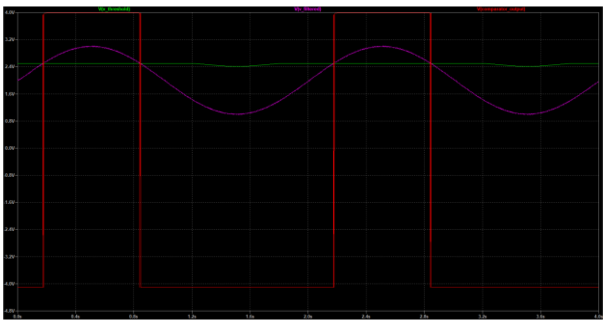

Figure 9: Comparator Output vs Simple Sine Signal (LTSpice)

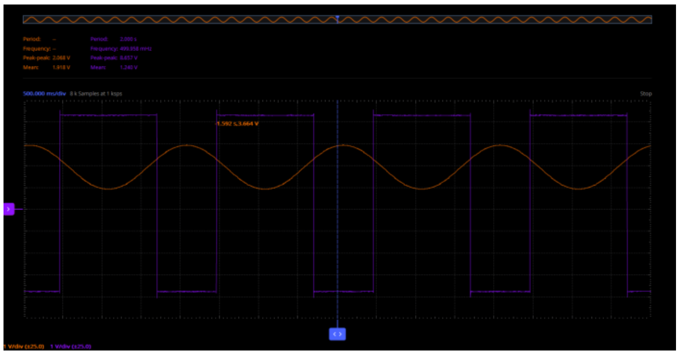

Figure 10: Comparator Output vs Simple Sine Signal (Scopy)

As shown in the figures above, the comparator output produce a high voltage when the input signal exceeds 2.5V. In this case, 2.5V is the threshold voltage. The threshold voltage can be tuned using the potentiometer as a voltage divider.

4.3 Single-Op-Amp Voltage-Controlled Oscillator (VCO)

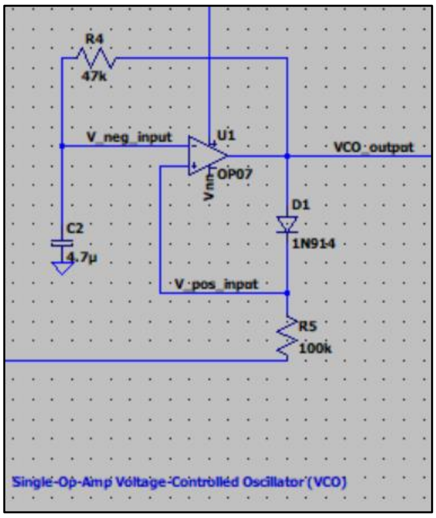

Figure 11: Single Op Amp Voltage Controlled Oscillator (LTSpice)

4.3.1 Function of VCO Subsystem

The VCO (Voltage Controlled Oscillator) is the most important subsystem in a reverse sensor. The VCO is responsible for generating an oscillating square waveform output which frequency is dependent on the filtered input signal.

4.3.2 The importance of a VCO in reverse vehicle sensors

4.3.2.1 Frequency Variation with Distance:

As the vehicle gets closer to an object, the input voltage increases, which in turn increases the frequency of the VCO output. This frequency modulation provides a clear and intuitive indication of the proximity of objects during reversing manoeuvres such as parking.

4.3.2.1.1 Audible and Visual Alert Generation

By converting the distance information into an oscillating waveform, the VCO enables us to produce an audible and visual alert that corresponds to the detected distance. This allows the driver to perceive the changing distance through the audible cues (beeping) and visual cues (light flashing). This enhances situational awareness and aids in making precise judgments during reverse operations.

4.3.3 Circuit Analysis

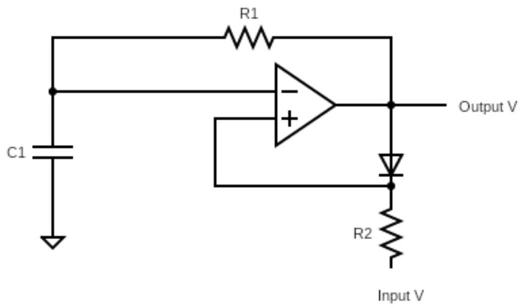

Figure 9: Circuit Design for VCO

The circuit work as VCO by using the comparator characteristic of the Op Amp. To understand the working principles let's consider the circuit.

Assume

$$VCO_{output} = +V_o$$

Hence

$$VCO_{+input} = V_o - V_{diode}$$

Capacitor starts charging.

VCO_-input increases from V_input (Signal)

When,

$$VCO_{-input} > VCO_{+input}$$

$$VCO_{output} = -V_o$$

Hence

$$VCO_{+input} = V_{input\_signal}$$

Capacitor starts discharging.

VCO_-input decreases.

$$VCO_{-input} < VCO_{+input}$$

$$VCO_{output} = +V_o$$

And the cycle repeats.

The frequency of the VCO output is dependant of two things.

$$1. time\ constant = R1 * C1$$

$$2. V_{cutoff} = V_{input\ signal}$$

Hence,

The frequency of the VCO is equal to the reciprocal of the time taken for the capacitor to charge from V_input_signal to (V_o – V_diode).

4.3.4 Simulation and Results

The figures below show the relationship between the inverting and non-inverting inputs of the VCO as well as the VCO output.

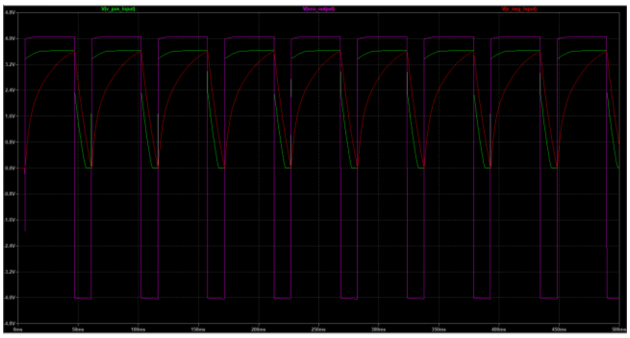

Figure 10: Inverting, Non-Inverting and Output of VCO (LTSpice)

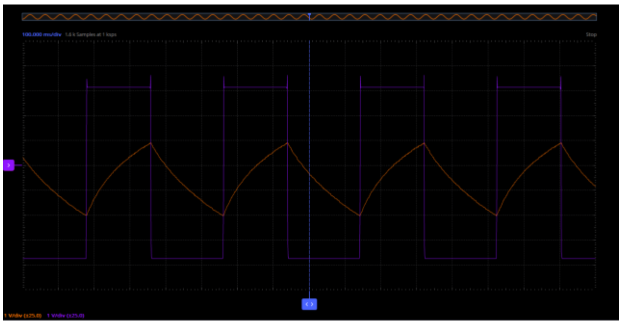

Figure 11: Inverting, Non-Inverting and Output of VCO (Scopy)

Figure below shows the varying frequency as V input signal increases.

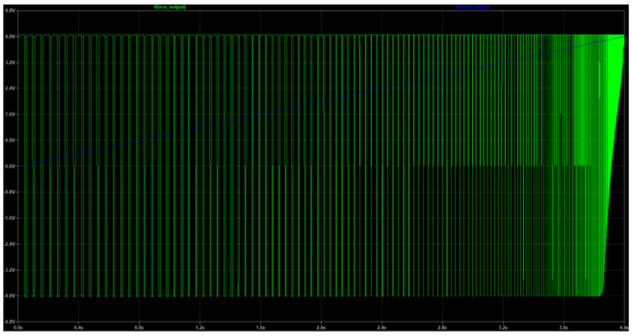

Figure 12: Varying frequency as Input voltage increases

This design is a single Op Amp VCO whereas most VCO's use a dual Op Amp set up. This requires less components (only requires one op amp), hence, it is more cost-effective. One characteristic of a single VCO is that it varies the duty cycle as well as the frequency. The disadvantage of this is that the duty cycle is not constant like a dual Op Amp VCO (50% duty cycle). This means that when the due cycle is too large, it will no longer be able to oscillate.

The table below shows the relationship between the input voltage, Output Frequency and Output duty cycle.

Table 1: Relationship between input voltage and output frequency & duty cycle

Input Voltage (V)	Output Frequency (Hz)	Output Duty Cycle (%)
0	18	71
0.5	19	75
1.0	20	80
1.5	22	82
2.0	24	85

2.5	28	88
3.0	38	92
3.5	71	96
4.0	N/A	100

The figure below shows the linearity of the Output frequency and duty cycle against the input voltage.

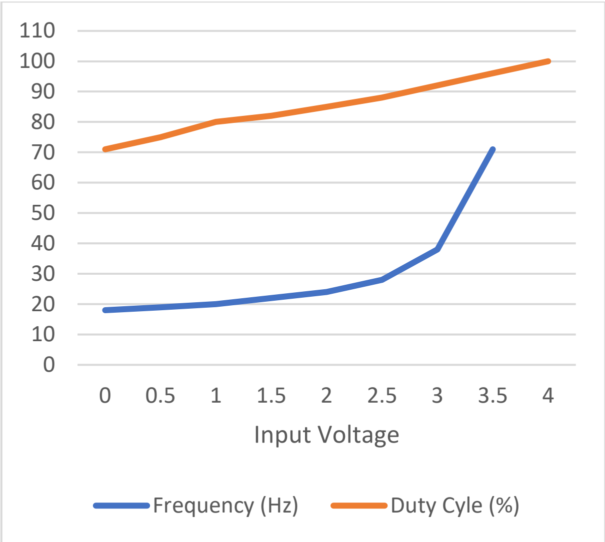

Figure 13: Linearity Output Frequency/Duty Cycle vs Input Voltage

As seen in the figure above the Frequency is not very linear and has more of an exponential increase whereas the Duty Cycle shows a linear relationship with the input Voltage.

At high Voltages the duty cycle becomes close to a 100 % hence, it may be difficult to observes oscillations. However, since the duty cycle is close to a 100%, the output can be assumed to be a constant high.

4.4 Transistor as switch

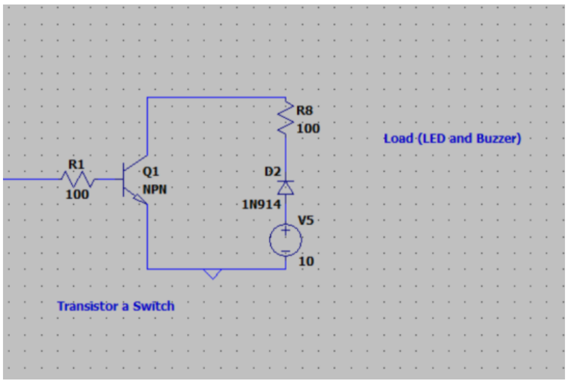

Figure 14: Transistor as Switch Circuit (LTSpice)

4.4.1 Function of transistor as switch

Using a transistor as a switch controls the on/off state of a load like an LED and buzzer.

Some Advantages of using a transistor as switch rather than directly connecting the VCO output to the load are as follows:

- Current amplification to ensure the efficiency of the Load circuit.
- Isolation between control circuit and Load that ensures protection for the control circuit.

4.4.2 Circuit Analysis

The transistor is connected in a specific configuration:

- Emitter: Load (Buzzer + LED)
- Collector: Positive Voltage Supply for Load
- Base: control Input (VCO output)

Controlling the base current turns the transistor on or off. The load (LED and buzzer) is connected in series with the collector and emitter terminals of the transistor.

4.4.3 Simulation and Results

The figure below shows the current being amplified by using a transistor as a switch.

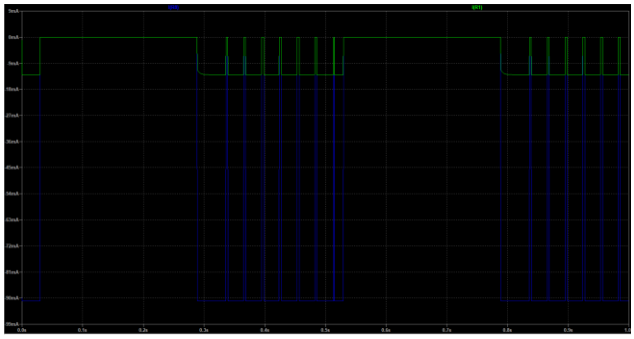

Figure 15: Current Amplified by using Transistor as Switch (LTSpice)

5 Component Analysis

Table 2: Component Analysis, Cost and Power Consumptions

Component	Model	LTSpice		Measured		Cost
		Peak Power (mW)	Average Power (mW)	Peak Power	Average Power	
R10		7.27	2.42	7.20	2.40	$0.60
R2		2.68	2.13	3.03	2.97	$3.74
R3	$P = \frac{v^2}{R}$	2.99	2.32	2.11	2.07	
R4		0.05	0.03	0.14	0.07	$0.60
R5		0.07	0.04	0.02	0.01	$0.55
R10		0.00	0.00	0.01	0.00	$0.60
C5/C2	P = 0	0.00	0.00	0.00	0.00	$1.90
3xLM741CN	Complex due to internal components					$2.37
Total		13.06	6.95	12.51	7.52	$10.36

The table above shows the power consumption and cost analysis of most of our components used both in LTSpice and in our physical circuit.

The utilization of LTSpice allows for the precise assessment of power consumption in various circuit components. Notably, the conducted measurements indicate a high level of correspondence between the simulated values and real-world simulations. This outcome underscores the effectiveness of LTSpice as a robust simulation program, offering a diverse range of options for OpAmps, transistors, and other components. Consequently, the software facilitates accurate theoretical simulations that closely resemble practical scenarios.

6 References

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[7] "Ultrasonic sensors: Answers to frequently asked questions," Banner Engineering, https://www.bannerengineering.com/my/en/company/expert-insights/ultrasonic-sensors-101.html#/ (accessed May 19, 2023).